Flare After Flare

Vinay Kashyap (SAO)
Jeremy Drake (SAO), David van Dyk (Imperial), Thomas Lee (UCDavis),
Raymond Wong (Iowa State)

Chandra Science for the neXt Decade, Cambridge MA, Aug 19 2016

Time-resolved spectroscopy of stellar flares with *Chandra* gratings

Vinay Kashyap (SAO)
Jeremy Drake (SAO), David van Dyk (Imperial), Thomas Lee (UCDavis),
Raymond Wong (Iowa State)

Chandra Science for the neXt Decade, Cambridge MA, Aug 19 2016

Outline

- Spectral variations during temporal variability
  - Automark
- Behavior of spectral lines during flare onset

Tracking spectral variations during temporal variability

EV Lac/1885

FK Com/12299

RT Cru/7186

ct/s

Time [+246104.537 ks]

Automark

- Derive changepoints in a marked Poisson process
- Like Bayesian Blocks, but in 2D and not Bayesian
  - The spectrum is modeled non-parameterically as a combination of 3rd degree polynomial radial basis continuum and δ-function lines
  - Number of changepoints in time determined via Minimum Description Length procedure with ℓ_1 penalty
- https://github.com/astrostat/Automark/

FKCom : 12299

0.25
0.20
0.15
0.10
0.05
[ct/s]

ACIS-S/MEG 0.6-7 keV

1×10⁴ 2×10⁴ 3×10⁴ 4×10⁴

Time [+420441791.4]

159 ph ^ 1635.4 s

(1) (2) (3) (4)

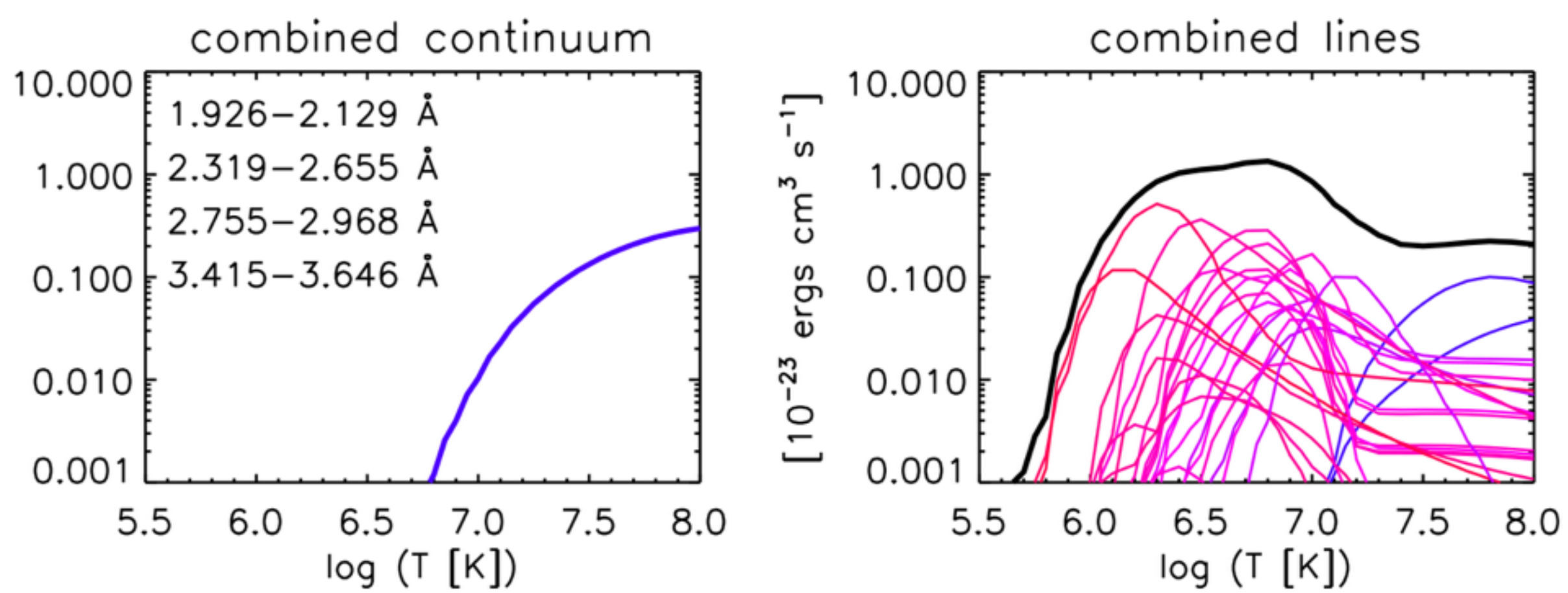
log₁₀ ratio of spectra

−0.5
−1.0
−1.5

5 10 15

Wavelength [Ang]

Spectral lines during flares



continuum ~3.4 - 6.4 keV : <logT>=7.70
1.85 Å : Fe XXV : <logT>=7.71
6.6-6.7 Å : Si XIII+ : <logT>=7.18
8.42 Å : Mg XII : <logT>=7.23
12.13 Å : Ne X : <logT>=6.95
13.57 Å : Ne IX+ : <logT>=6.84
15.01, 15.26, 16.06, 16.78, 17.09 Å
: Fe XVII + : <logT>=6.80
18.96 Å : O VIII : <logT>=6.44
21.5-22.2 Å : O VII : <logT>=6.39

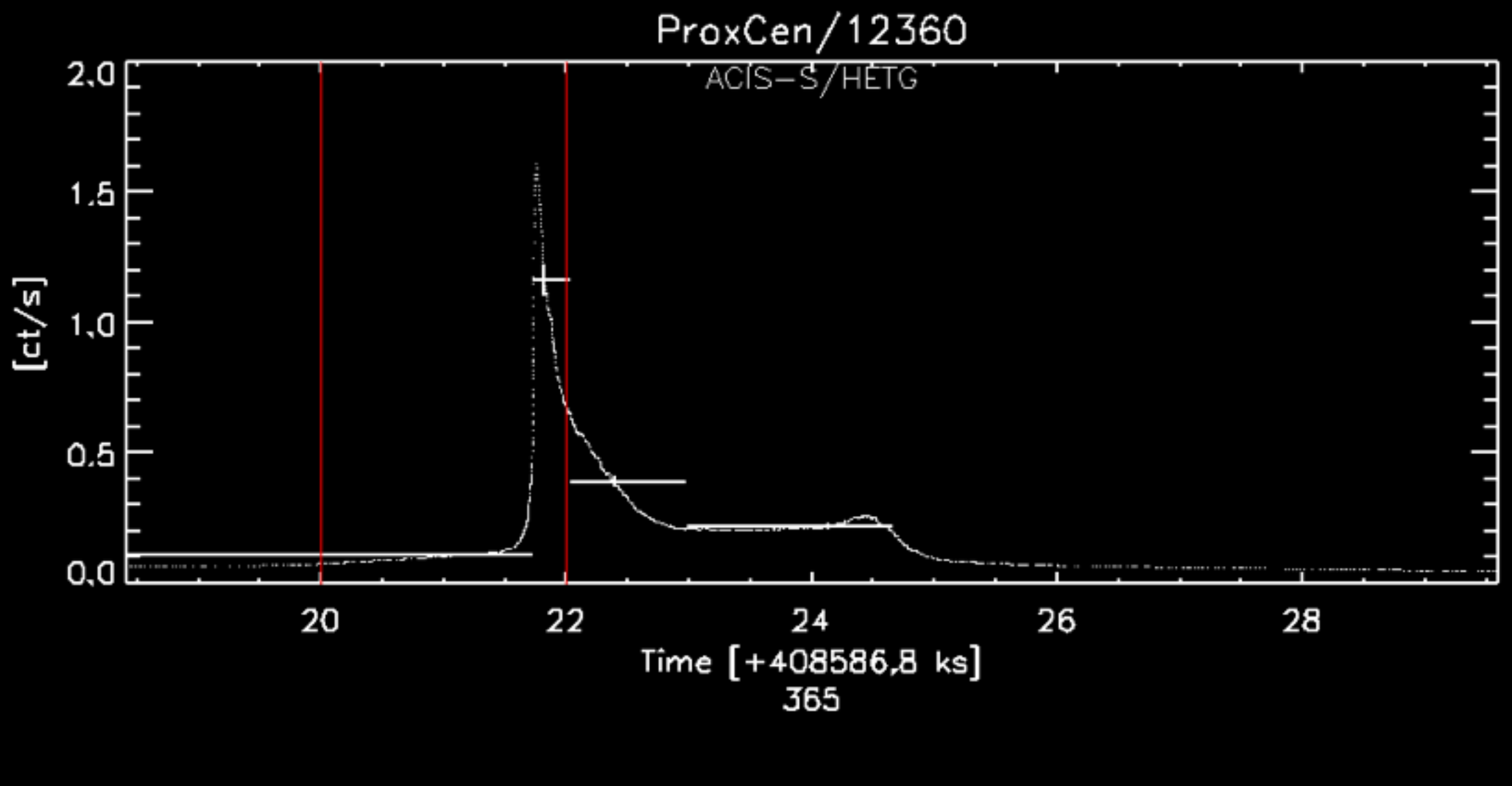
A zoo of flares

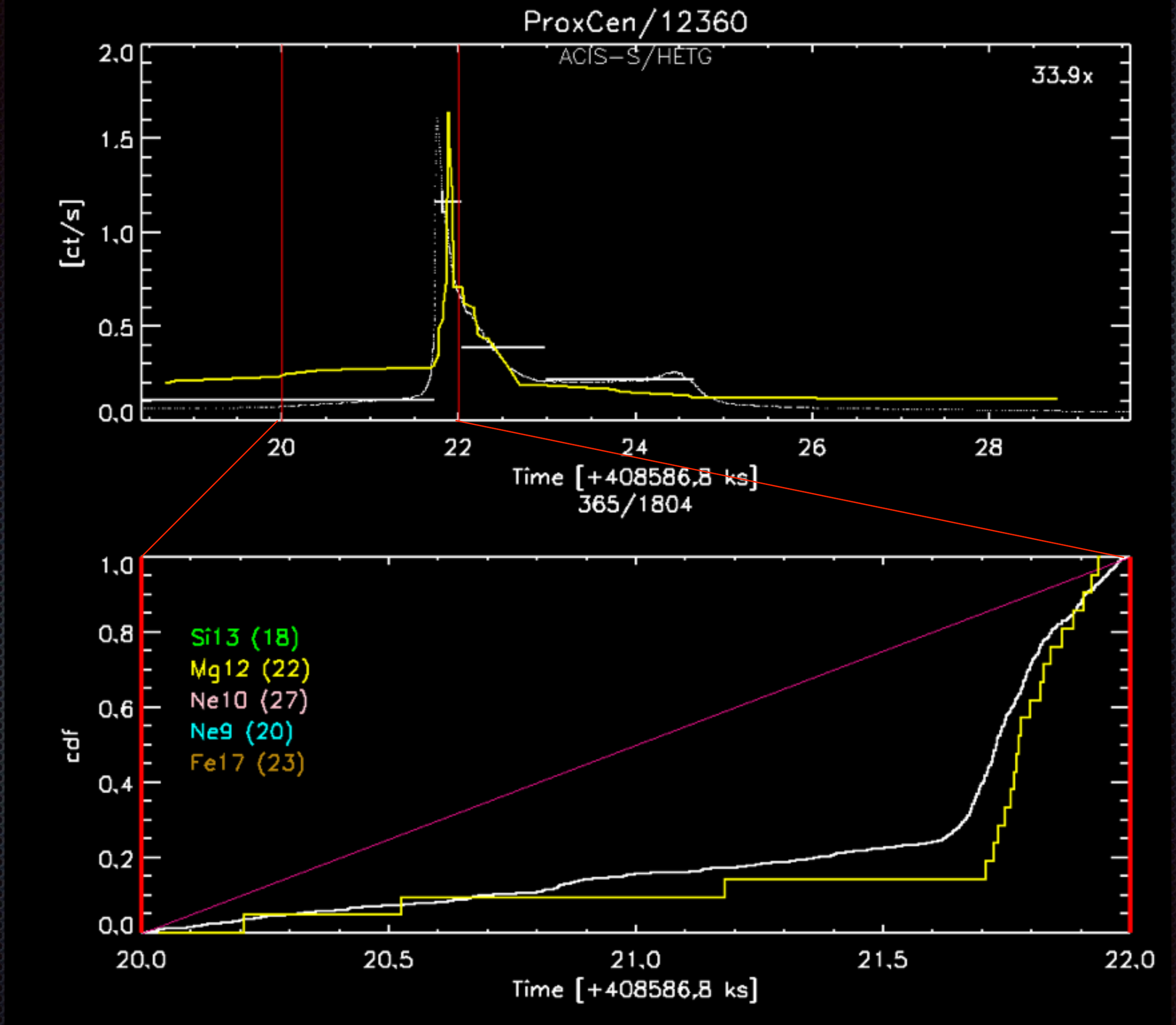
>70 strong flares in ~3.5 Msec

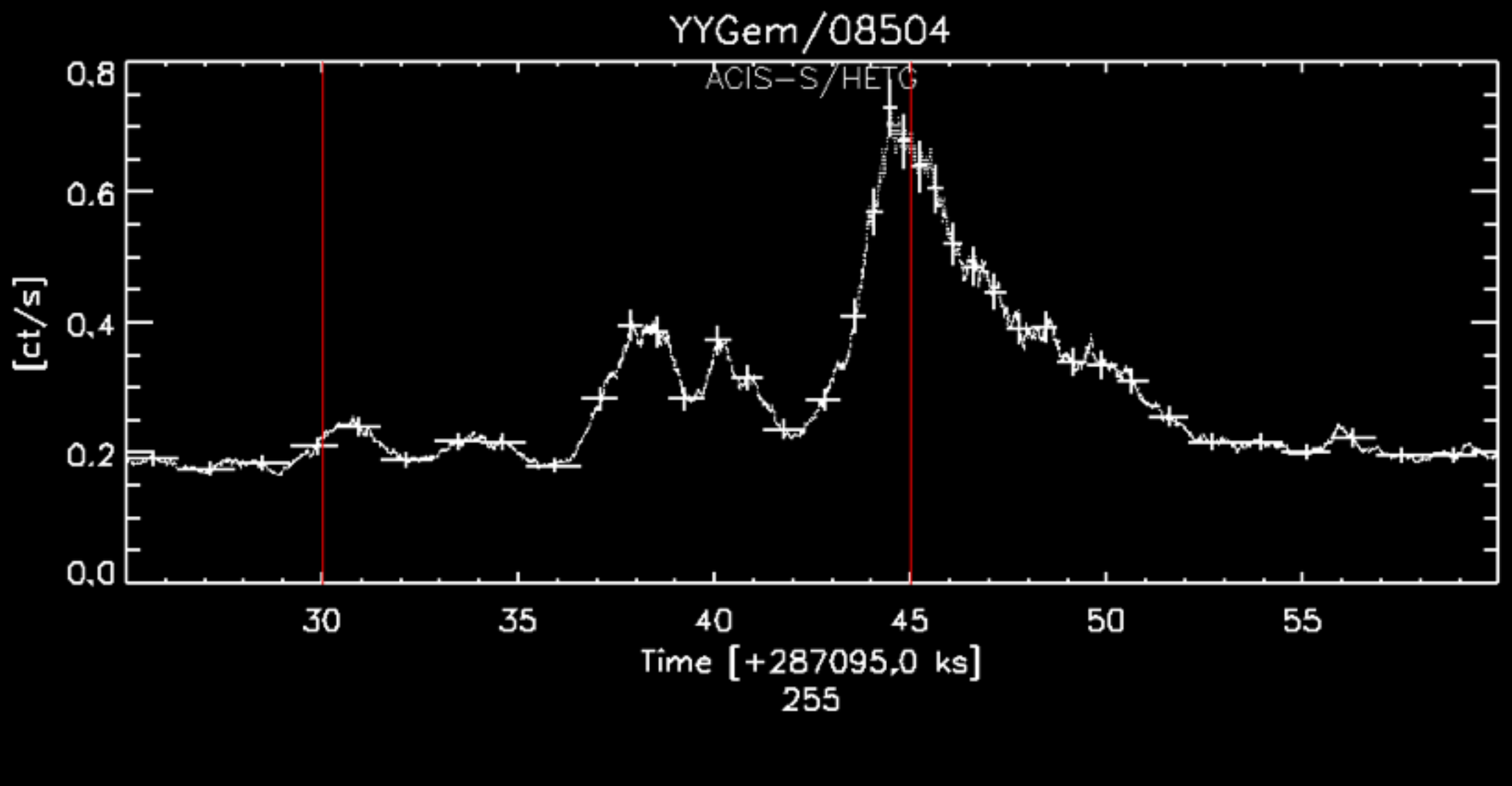
Intensity changes are not synchronized across wavelength

Higher temperature plasma invariably *lags* the full band flare

Bursts sometimes occur in some lines preceding the full band flare


ProxCen/12360
ACIS-S/HETG
[ct/s]
2.0
1.5
1.0
0.5
0.0
20
22
24
26
28
Time [+408586.8 ks]


ProxCen/12360
ACIS-S/HETG
33.9x
[ct/s]
2.0
1.5
1.0
0.5
0.0
20
22
24
26
28
Time [+408586.8 ks]
365/1804
cdf
1.0
0.8
0.6
0.4
0.2
0.0
Si13 (18)
Mg12 (22)
Ne10 (27)
Ne9 (20)
Fe17 (23)
20.0
20.5
21.0
21.5
22.0
Time [+408586.8 ks]


YYGem/08504
ACIS-S/HETG
0.8
0.6
0.4
0.2
0.0
[ct/s]
30
35
40
45
50
55
Time [+287095.0 ks]

YYGem/08504

ACIS-S/HETG

4.4x

[ct/s]

0.0
0.2
0.4
0.6
0.8

30
35
40
45
50
55

Time [+287095.0 ks]

255/9794

cdf

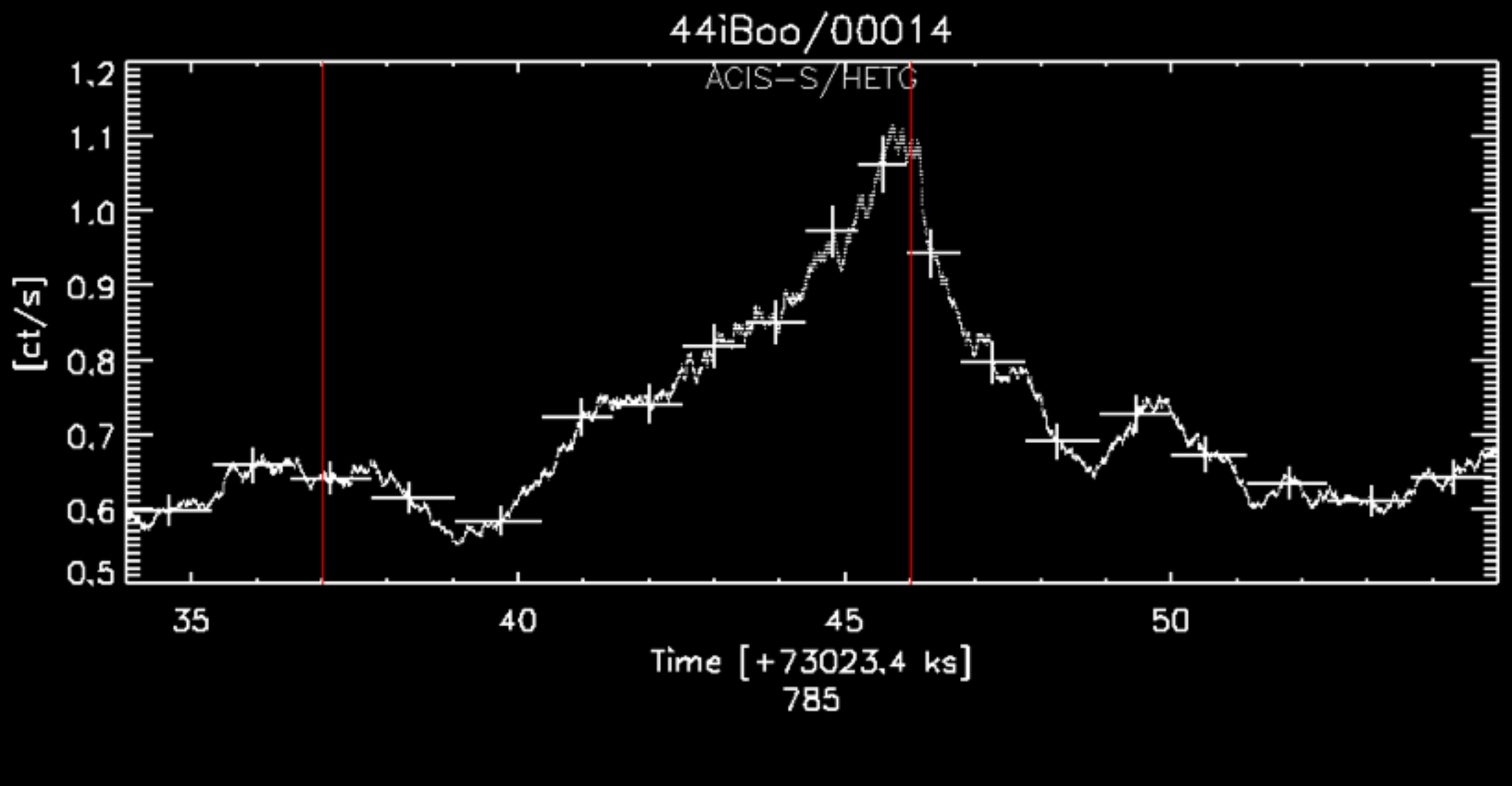
0.0
0.2
0.4
0.6
0.8
1.0

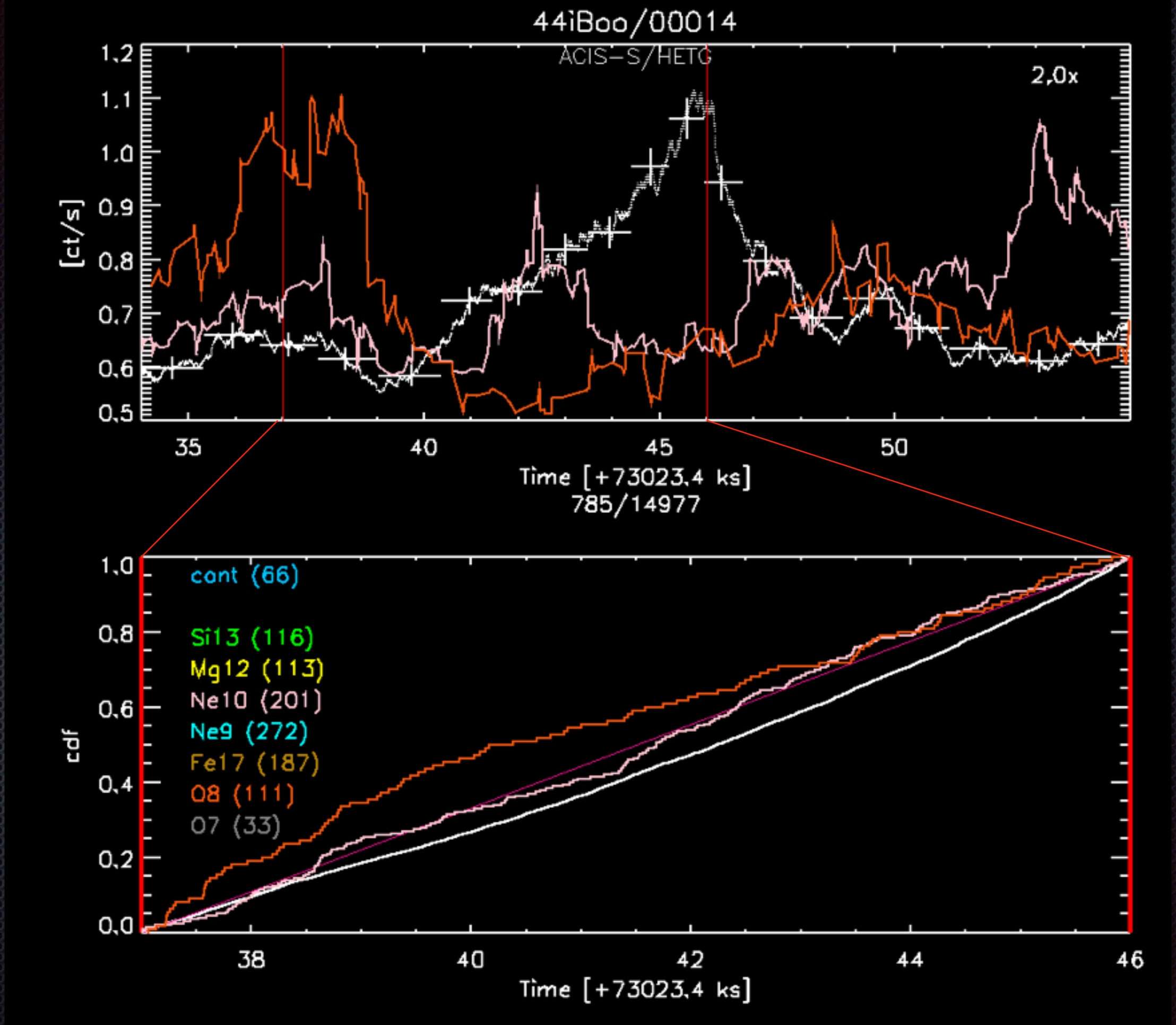
cont (64)

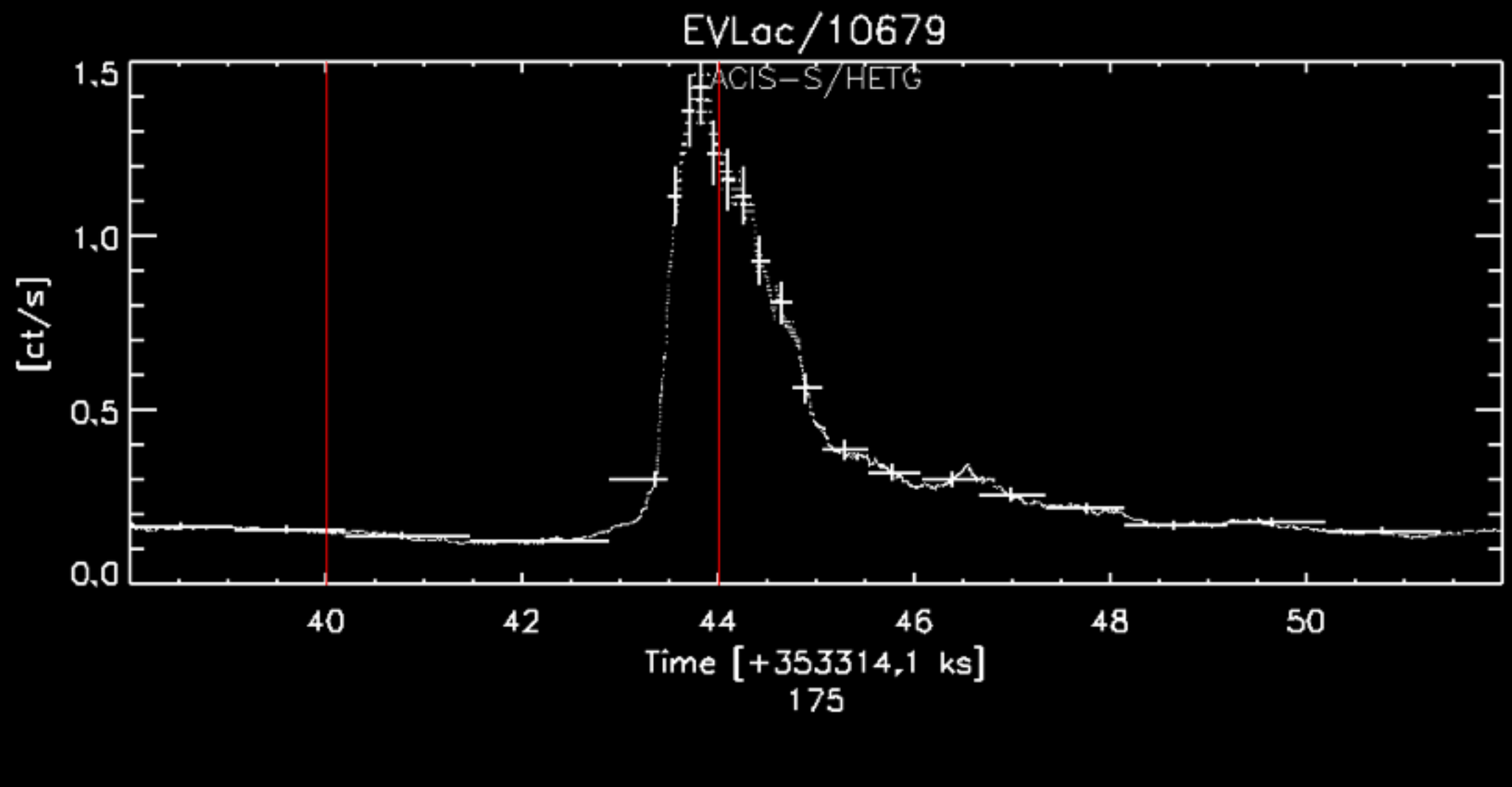
Si13 (111)
Mg12 (84)
Ne10 (219)
Ne9 (187)
Fe17 (160)
O8 (64)
O7 (22)

30
32
34
36
38
40
42
44

Time [+287095.0 ks]


44iBoo/00014
ACIS-S/HETG
[ct/s]
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
35
40
45
50
Time [+73023.4 ks]


44iBoo/00014
ACIS-S/HETG
2.0x
[ct/s]
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
35
40
45
50
Time [+73023.4 ks]
785/14977
cont (66)
Si13 (116)
Mg12 (113)
Ne10 (201)
Ne9 (272)
Fe17 (187)
O8 (111)
O7 (33)
cdf
1.0
0.8
0.6
0.4
0.2
0.0
38
40
42
44
46
Time [+73023.4 ks]


EVLac/10679
ACIS-S/HETG
1.5
1.0
0.5
0.0
[ct/s]
40
42
44
46
48
50
Time [+353314.1 ks]

EVLac/10679

ACIS-S/HETG

12.4x

[ct/s]

1.5
1.0
0.5
0.0

40 42 44 46 48 50

Time [+353314.1 ks]

175/3947

cdf

1.0
0.8
0.6
0.4
0.2
0.0

cont (32)
Si13 (20)
Mg12 (18)
Ne10 (43)
Ne9 (38)
Fe17 (30)
O8 (15)

40 41 42 43 44

Time [+353314.1 ks]

Trends and tendencies

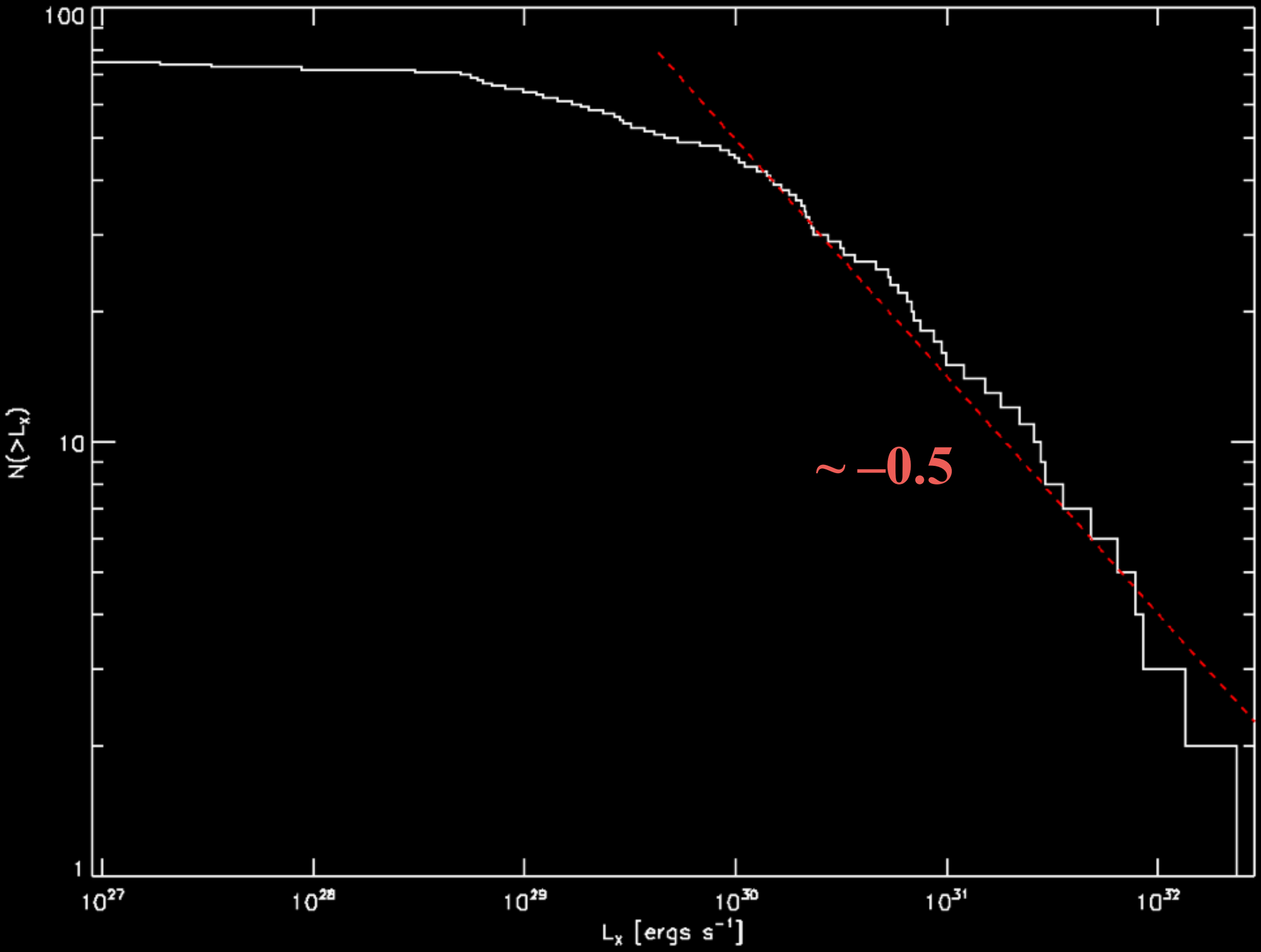
Intensity changes are not synchronized across wavelength — many lines have peak intensities later, or show no response at all, or show small burst at beginning

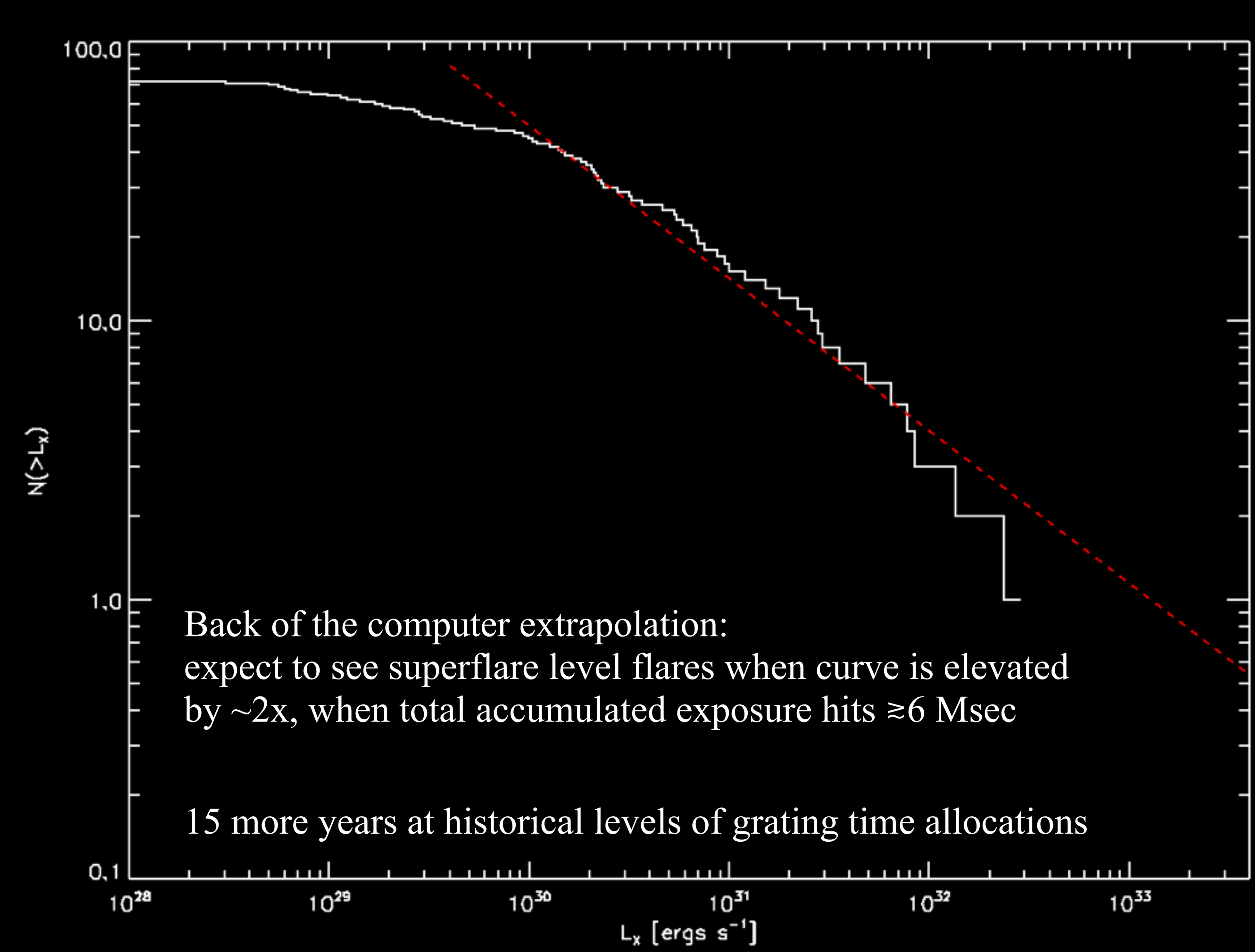
Higher temperature plasma invariably *lags* the full band flare — even if it starts at the same time, picks up 100s of seconds later, so standard model of T-n_e evolution (first increase T, then n_e) needs rethink

Summary

- Looking at high-resolution spectra at the events level can yield rich information on flare dynamics
- Emission line evolution is complex and does not always track the overall intensity
- Spectra harden during the rise phase, indicating plasma temperatures increase slowly, and really high temperature plasma (>10 MK) lags flare onset appreciably, by many 100s of seconds
  - Unlike typical flare models where first there is an increase in T, then an increase in brightness
- Analysis is currently limited by model assumptions, small counts, pre-existing conditions (e.g., residues of previous flares)

One more thing.. flares in ensemble


100
10
1
N(>Lx)
~ –0.5
10^27
10^28
10^29
10^30
10^31
10^32
Lx [ergs s^-1]


100.0
10.0
1.0
0.1
N(>Lx)
10^28
10^29
10^30
10^31
10^32
10^33
Lx [ergs s^-1]
Back of the computer extrapolation:
expect to see superflare level flares when curve is elevated
by ~2x, when total accumulated exposure hits ≳6 Msec
15 more years at historical levels of grating time allocations

Summary

- Looking at high-resolution spectra at the events level can yield rich information on flare dynamics
- Emission line evolution is complex and does not always track the overall intensity
- Spectra harden during the rise phase, indicating plasma temperatures increase slowly, and really high temperature plasma (>10 MK) lags flare onset appreciably, by many 100s of seconds
  - Unlike typical flare models where first there is an increase in T, then an increase in brightness
- Analysis is currently limited by model assumptions, small counts, pre-existing conditions (e.g., residues of previous flares)